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Winkler

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(54) **METHOD AND SYSTEMS FOR IN-SITU FORMATION OF INTERMEDIATE REACTIVE SPECIES**

(71) Applicant: **ASM IP Holding B.V.**, Almere (NL)

(72) Inventor: **Jereld Lee Winkler**, Gilbert, AZ (US)

(73) Assignee: **ASM IP Holding B.V.**, Almere (NL)

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(58) **Field of Classification Search**

USPC .... 118/715, 723 ME, 723 IR, 723 ER; 156/345.33, 345.34, 345.35

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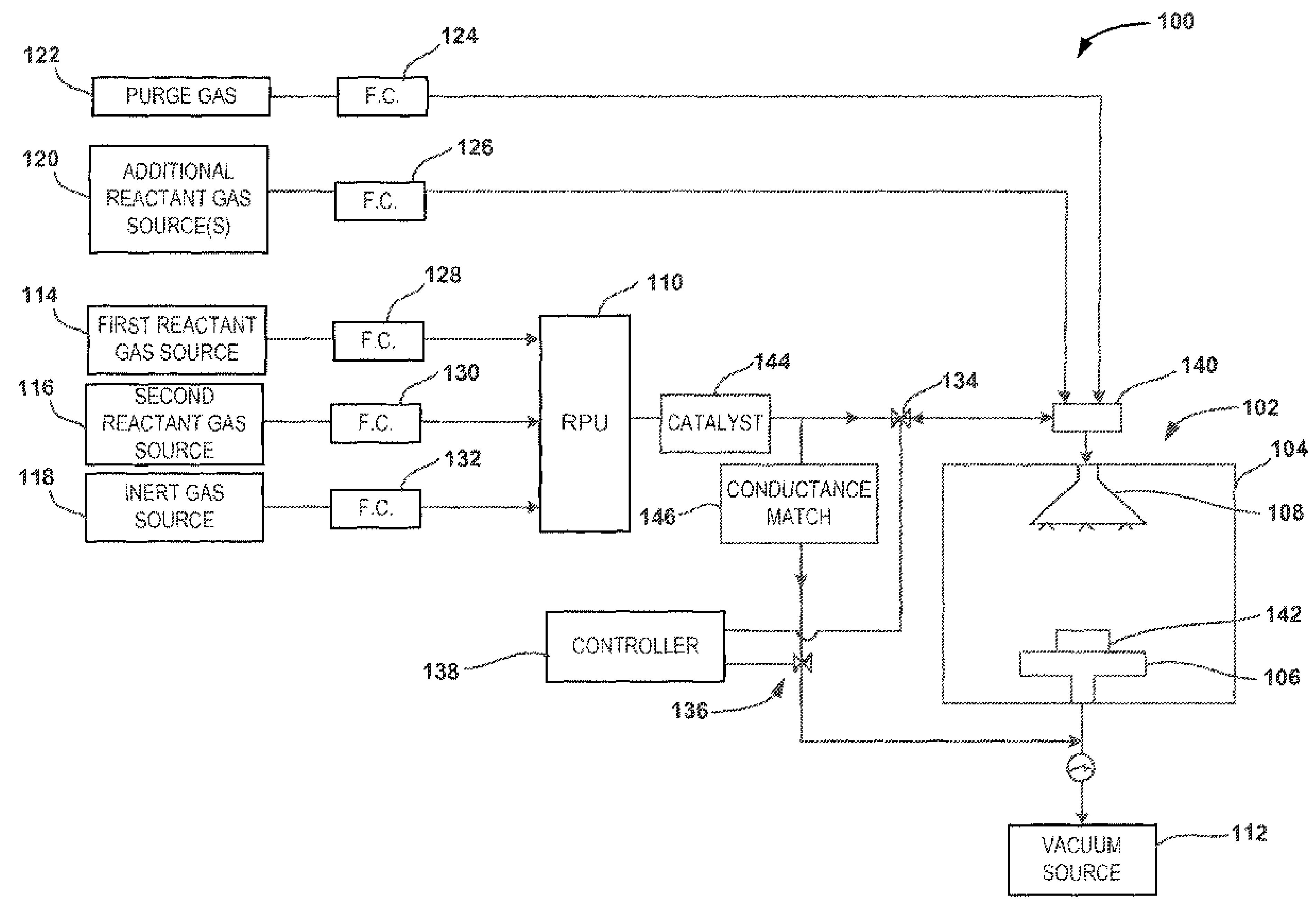
Primary Examiner — Rakesh Dhingra
(74) *Attorney, Agent, or Firm* — Snell & Wilmer L.L.P.

(57) **ABSTRACT**

A system and method for providing intermediate reactive species from a remote plasma unit to a reaction chamber are disclosed. The system includes a pressure control device to control a pressure at the remote plasma unit as intermediate reactive species from the remote plasma unit are provided to the reaction chamber.

20 Claims, 2 Drawing Sheets



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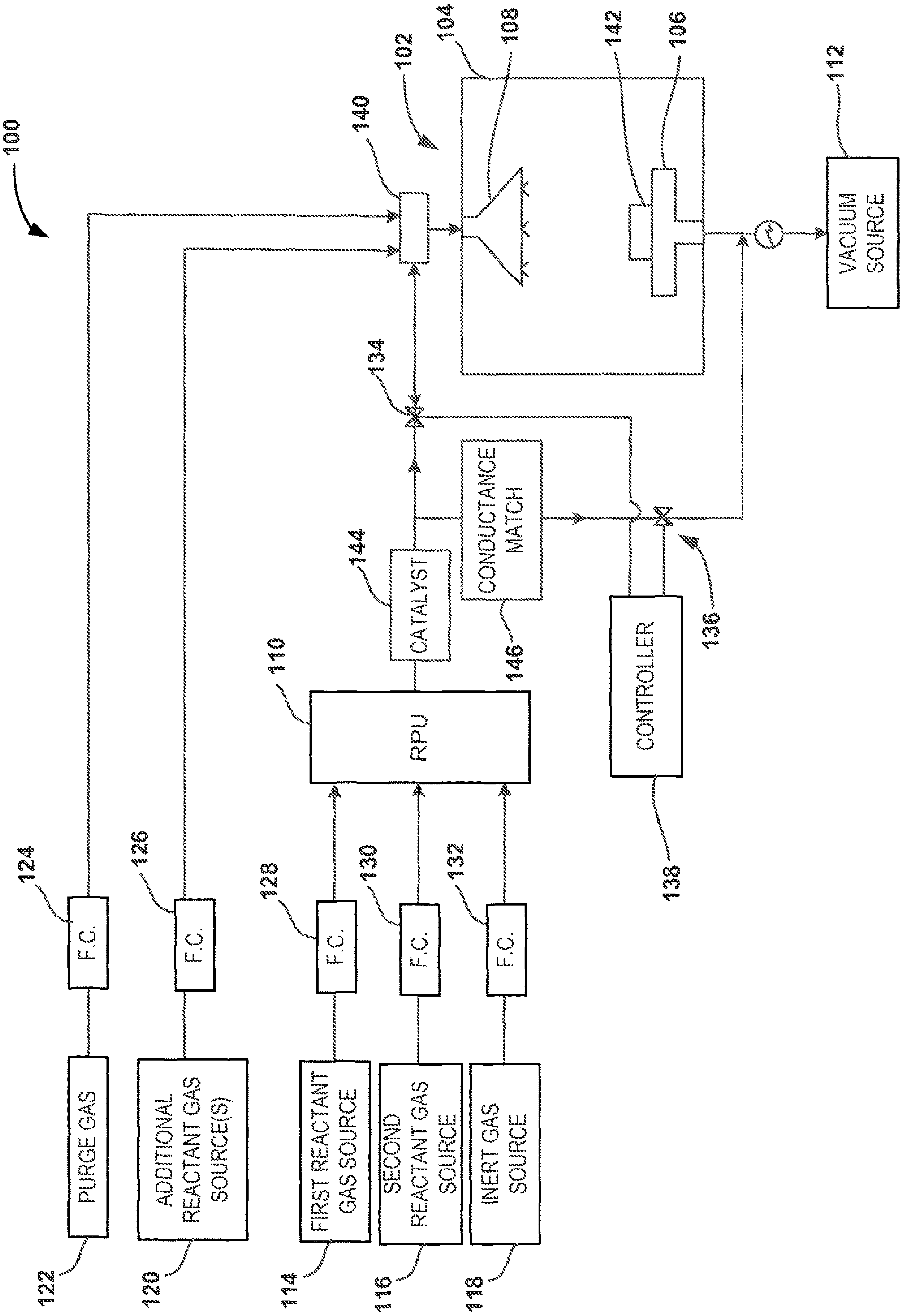
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102
104
108
142
106
112
VACUUM SOURCE
140
134
CONDUCTANCE MATCH
146
144
CATALYST
110
RPU
CONTROLLER
138
136
124
F.C.
126
F.C.
128
F.C.
130
F.C.
132
F.C.
PURGE GAS
122
ADDITIONAL REACTANT GAS SOURCE(S)
120
FIRST REACTANT GAS SOURCE
114
SECOND REACTANT GAS SOURCE
116
INERT GAS SOURCE
118

FIG. 1

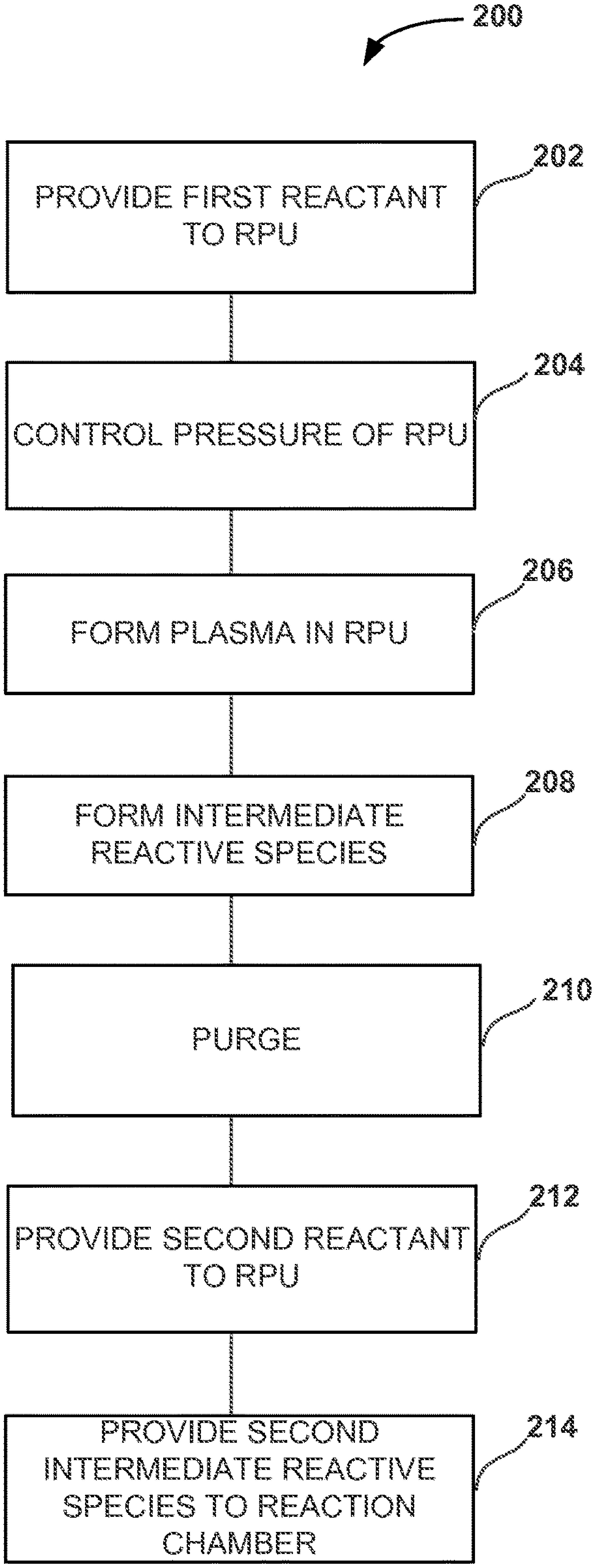
200
PROVIDE FIRST REACTANT TO RPU
202
CONTROL PRESSURE OF RPU
204
FORM PLASMA IN RPU
206
FORM INTERMEDIATE REACTIVE SPECIES
208
PURGE
210
PROVIDE SECOND REACTANT TO RPU
212
PROVIDE SECOND INTERMEDIATE REACTIVE SPECIES TO REACTION CHAMBER
214

FIG. 2

METHOD AND SYSTEMS FOR IN-SITU FORMATION OF INTERMEDIATE REACTIVE SPECIES

FIELD OF INVENTION

The disclosure generally relates to vapor-phase methods and systems. More particularly, exemplary embodiments of the present disclosure relate to systems and methods for forming intermediate reactive species useful in vapor-phase processes.

BACKGROUND OF THE DISCLOSURE

Vapor-phase processes are used for a variety of applications. For example, vapor-phase processes are used for chemical vapor deposition to deposit material onto a substrate, vapor-phase etching to remove material from a substrate or a reactor, and vapor-phase treatment processes to treat a surface of a substrate or a reactor.

Precursors or reactants for vapor-phase processes are generally selected according to a material to be deposited, etched, or treated; i.e., the precursors are generally selected to provide desired vapor-phase reactants. However, other factors are often used to select between more than one precursor that might be suitable for a particular application. For example, a reactivity or selectivity of a precursor may be a factor in the selection of the precursor. Another consideration for selecting a precursor is the stability of the precursor—e.g., does the precursor break down into other compounds before the precursor has a chance to take part in a desired reaction. Yet further considerations may include toxicity of a precursor, availability of the precursor, and cost of the precursor. Thus, a precursor that might have better properties, such as higher selectivity, reactivity, and/or provide more uniform deposition, etch, or treatment, may not be selected for a particular application, because the precursor is relatively expensive and/or toxic.

Remote or direct plasma systems may be used to create activated or energized species from a precursor, where the energized species are more reactive than the precursor for a given temperature. Remote plasma systems generally form a plasma upstream of a reaction chamber, and direct plasma systems generally form a plasma within a reaction chamber, where a substrate is often in or adjacent the plasma. Remote plasma systems may be advantageous over direct plasma systems for some applications, because the remote plasma systems do not form a plasma directly over a surface of a substrate. As a result, surface damage to a substrate that might otherwise occur in a direct plasma reactor can be reduced or eliminated using a remote plasma. However, remote plasma activated species from many precursors are relatively short lived and recombine or react with other components before the species enter the reaction chamber or reach a desired area of a substrate (e.g., a lower portion of a trench formed on a surface of the substrate and/or an outer perimeter of the substrate). Using a direct plasma allows the activated species to form within the reaction chamber, but the activated species may still recombine or otherwise become inactivated prior to reacting desired areas on a substrate.

Accordingly, improved methods and systems for forming desired, relatively stable intermediate reactive species, using a remote plasma system are desired.

SUMMARY OF THE DISCLOSURE

Various embodiments of the present disclosure provide improved methods and systems for providing intermediate reactive species from one or more precursors using a remote plasma unit. Exemplary methods and systems can be used to form intermediate reactive species near a reaction chamber, where, for example, the intermediate reactive species might be considered a desirable reactant but an undesirable precursor. Thus, the method and system can be used to provide a steady-state source of desired reactants. While the ways in which the various drawbacks of the prior art are discussed in greater detail below, in general, the methods and systems described herein provide remote plasma systems having relatively stable, desired reactants formed using a remote plasma unit.

In accordance with various embodiments of the disclosure, a remote plasma system includes a reactor having a reaction chamber, a remote plasma unit fluidly coupled to the reaction chamber and to a vacuum source, a first gas source fluidly coupled to the remote plasma unit, wherein the first gas source includes a precursor for intermediate reactive species, a pressure control device in fluid communication with and interposed between the remote plasma unit and the vacuum source, wherein the pressure control device controls an operating pressure of the remote plasma unit, and a control valve between the remote plasma unit and the reaction chamber. The reactor may be, for example, a plasma-enhanced chemical vapor deposition reactor, a plasma-enhanced atomic layer deposition reactor, a plasma-enhanced etch reactor, a plasma-enhanced clean reactor, or a plasma-enhanced treatment reactor. In accordance with various aspects of these embodiments, the system further includes a controller coupled to the pressure control device and/or the control valve to maintain a desired operating pressure of the remote plasma unit. In accordance with further aspects, the system includes one or more flow control units (e.g., mass flow controllers) to control flow rates of one or more gasses to the remote plasma unit. In accordance with further aspects, the pressure control device is a closed-loop pressure controller that controls a gas pressure upstream of the pressure control device. In accordance with additional aspects, the control valve is a fast-response pneumatic valve. And, in accordance with yet additional aspects, the system further comprises an integrated inlet manifold block between the remote plasma unit and the reactor. The system may also include a catalyst between the remote plasma unit and the reaction chamber (and optionally the vacuum source) to facilitate formation of desired intermediate reactants. And, in accordance with additional aspects, the system includes a conductance match region between the remote plasma unit and the vacuum source.

In accordance with additional exemplary embodiments of the invention, a method for providing intermediate reactive species to a reaction chamber of a reactor includes the steps of providing a first gas to the remote plasma unit, controlling a pressure of the remote plasma unit, forming a plasma in a remote plasma unit, and forming intermediate reactive species from the first gas using the remote plasma unit, while maintaining steady-state conditions for the remote plasma unit. Exemplary methods in accordance with these embodiments can be used for depositing material onto a surface of a substrate, etching a material on a surface of a substrate, cleaning a surface of a substrate, treating a surface of a substrate, treating a surface of the reaction chamber, or cleaning a surface of the reaction chamber. In accordance with various aspects of these embodiments, the method additionally includes providing a second reactant to the remote plasma unit to form a second intermediate reactive species, and providing the second intermediate reactive species to the reaction chamber. In accordance with further aspects, the step of controlling a pressure of the remote plasma unit comprises using a closed-loop upstream pressure controller. In accordance with further aspects, the step of forming a plasma in a remote plasma unit includes forming a plasma using a unit selected from the group consisting of an inductively coupled plasma unit and a microwave unit. In accordance with yet further aspects, the step of forming intermediate reactive species from the first gas and/or the step of providing the second intermediate reactive species includes controlling a valve between the remote plasma unit and the reaction chamber.

In accordance with yet additional embodiments of the invention, a plasma-enhanced chemical vapor deposition system, such as a plasma-enhanced atomic layer deposition reactor includes a deposition reactor comprising a reaction chamber, a remote plasma unit fluidly coupled to the reaction chamber and to a vacuum source, a first reactant source coupled to the remote plasma unit, wherein the first reactant gas source is a precursor for intermediate reactive species, a pressure control device in fluid communication with and interposed between the remote plasma unit and the vacuum source, wherein the pressure control device controls an operating pressure of the remote plasma unit, and a control valve between the remote plasma unit and the reaction chamber. In accordance with various aspects of these embodiments, the system further includes a controller coupled to the pressure control device and/or the control valve to maintain a desired operating pressure of the remote plasma unit. In accordance with further aspects, the system includes one or more flow control units to control flow rates of one or more gasses to the remote plasma unit. In accordance with further aspects, the pressure control device is a closed-loop pressure controller that controls a gas pressure upstream of the pressure control device. In accordance with additional aspects, the control valve is a fast-response pneumatic valve. And, in accordance with yet additional aspects, the system further comprises an integrated inlet manifold block between the remote plasma unit and the reactor. In accordance with yet additional aspects of these embodiments, the system includes a catalyst between the remote plasma unit and the reaction chamber (and optionally the vacuum source) to facilitate formation of desired intermediate reactants. And, in accordance with additional aspects, the system includes a conductance match region between the remote plasma unit and the vacuum source.

Both the foregoing summary and the following detailed description are exemplary and explanatory only and are not restrictive of the disclosure or the claimed invention.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

A more complete understanding of the embodiments of the present disclosure may be derived by referring to the detailed description and claims when considered in connection with the following illustrative figures.

FIG. **1** illustrates a system in accordance with various exemplary embodiments of the disclosure.

FIG. **2** illustrates a method in accordance with exemplary embodiments of the disclosure.

It will be appreciated that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of illustrated embodiments of the present disclosure.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS OF THE INVENTION

The description of exemplary embodiments of methods and systems provided below is merely exemplary and is intended for purposes of illustration only; the following description is not intended to limit the scope of the disclosure or the claims. Moreover, recitation of multiple embodiments having stated features is not intended to exclude other embodiments having additional features or other embodiments incorporating different combinations of the stated features.

The methods and systems include use of a remote plasma unit to form intermediate reactive species. In accordance with various exemplary embodiments, the remote plasma unit operates at substantially steady-state conditions, even when gas-phase reactant(s) from the remote plasma unit are pulsed to a reaction chamber of a reactor by switching a flow of the reactants(s) between the reaction chamber and a vacuum source. Because the remote plasma unit operates at substantially steady-state conditions, the stability of the plasma is improved, throughput of the system is increased, and uniformity of activated species from the remote plasma unit is increased. The terms activated species and excited species are used interchangeably herein.

Turning now to FIG. **1**, an exemplary remote plasma system **100**, for providing intermediate reactive species, is illustrated. System **100** includes a reactor **102**, including a reaction chamber **104**, a substrate holder **106**, a gas distribution system **108**, a remote plasma unit **110**, a vacuum source **112**, a first reactant gas source **114**, optionally a second reactant gas source **116**, an inert gas source **118**, optionally one or more additional reactant gas source(es) **120**, optionally a purge gas source **122**, one or more flow controllers **124-132**, a control valve **134**, a pressure control device **136**, and optionally a controller **138** coupled to control valve **134** and/or pressure control device **136**. System **100** may also optionally include an integrated inlet manifold block **140**, a catalyst **144**, and/or a conductance match region **146**.

Reactor **102** may be used to deposit material onto and/or etch material from a surface of a substrate **142**. Reactor **102** may be a standalone reactor or part of a cluster tool. Further, reactor **102** may be dedicated to deposition, etch, clean, or treatment processes as described herein, or reactor **102** may be used for multiple processes—e.g., for any combination of deposition, etch, clean, and treatment processes.

For example, reactor **102** may include a reactor typically used for plasma-enhanced chemical vapor deposition (PECVD) and/or plasma-enhanced atomic layer deposition (PEALD) processing. Although not illustrated, system **100** may additionally include thermal excitation for one or more reactants.

Substrate holder **106** is designed to hold substrate or workpiece **142** in place during processing. In accordance with various exemplary embodiments, holder **106** may form part of a direct plasma circuit. Additionally or alternatively, holder **106** may be heated, cooled, or be at ambient process temperature during processing.

Although gas distribution system **108** is illustrated in block form, gas distribution system **108** may be relatively complex and be designed to mix vapor (gas) from sources **114**, **116**, **120** and/or carrier/purge gases from one or more sources **118**, **122** prior to distributing the gas mixture to reaction chamber **104**. Further, system **108** may be configured to provide vertical (as illustrated) or horizontal flow of gasses to the chamber **104**. An exemplary gas distribution system is described in U.S. Pat. No. 8,152,922 to Schmidt et al., issued Apr. 10, 2012, entitled "Gas Mixer and Manifold Assembly for ALD Reactor," the contents of which are hereby incorporated herein by reference, to the extent the contents do not conflict with the present disclosure. By way of example, distribution system **108** may include a showerhead.

Remote plasma unit **110** is a remote plasma device that includes a reaction chamber and at least two electrodes coupled to a power source, which is capable of forming a plasma. By way of particular examples, the remote plasma unit may be an inductively coupled plasma unit or a microwave remote plasma unit. The plasma is used to form intermediate reactive species from gas sources **114-116**.

Vacuum source **112** may include any suitable vacuum source capable of providing a desired pressure in reaction chamber **104**. Vacuum source **112** may include, for example, a dry vacuum pump alone or in combination with a turbo molecular pump. Although illustrated with reactor **102** and remote plasma unit **110** coupled to the same vacuum source, reactor **102** and remote plasma unit **110** may suitably be coupled to separate vacuum sources.

Reactant gas sources or precursors **114**, **116**, and **120** may each include one or more gases, or materials that become gaseous, that are used in deposition, etch, clean, or treatment processes. Exemplary gas sources include ammonia (NH_3), water vapor (H_2O). hydrogen peroxide (H_2O_2), MMH (mono methyl hydrazine), UDMH (unsymmetrically dimethyl hydrazine), O_2/H_2, N_2/H_2, and H_2S.

As noted above, system **100** can be used to form intermediate reactive species from one or more precursors from a gas source. Because system **100** can form intermediate reactive species, precursors (e.g. precursors **114**, **116**) may have relatively desirable precursor qualities—e.g., be relatively safe, inexpensive, etc., while the intermediate reactive species may have more desirable reactant qualities—e.g., be relatively stable and provide relatively even deposition or etch characteristics across a surface of a substrate and/or within a reaction chamber. Exemplary intermediate reactive species formed from ammonia include, for example, hydrazine (N_2H_4), NH_2, which is relatively unstable, and diazene (N_2H_2). Both hydrazine and diazene are considered toxic and are not typically used in vapor deposition processes. However, both hydrazine and diazene have superior properties when forming nitride materials using vapor deposition processing. The present invention allows for the safe, easy formation of these intermediate reactive species. Similarly, OH— intermediate reactive species from H_2O may be formed using the system described herein. Additional intermediate reactive species include H_2O_2 (peroxide), HO_2, NH, NH_2, N_2H, and HS from H_2S and excited species thereof.

In the context of reactor etching or cleaning, the relatively stable intermediates that are formed can be used to etch or clean reactor parts, such as a fore line, that might otherwise not be cleaned or etched with less stable reactants.

Inert source **118** and purge gas **122** include one or more gases, or materials that become gaseous, that are relatively unreactive in reactor **102**. Exemplary inert and purge gasses include nitrogen, argon, helium, and any combinations thereof.

Flow controllers **124-132** may include any suitable device for controlling gas flow. For example, flow controllers **124-132** may be mass flow controllers.

Control valve **134** is positioned between remote plasma unit **110** and reaction chamber **104**. During operation of system **100**, control valve **134** can be opened and closed to pulse excited species from remote plasma unit **110** to reaction chamber **104**. Valve **134** may be controlled using controller **138** and may be operated independently of process control device **136** or in coordination with process control device **136** to facilitate steady-state operation of remote plasma unit **110**. By way of example, control valve **134** is a fast-response diaphragm pneumatic valve.

Pressure control device **136** controls pressure upstream of device **136**, such that remote plasma unit **110** can operate under steady-state conditions even as activated species from remote plasma unit **110** are pulsed to reaction chamber **104**—e.g., using control valve **134** to pulse the activated species to reaction chamber **104**. Pressure control device **136** may include any suitable device that controls an upstream pressure. By way of example, pressure control device **136** is a closed-loop pressure controller, such as MKS model 640A pressure controller. Alternatively, pressure control device may include a throttle valve.

In the illustrated example, pressure control device **136** and control valve **134** are controlled (opened and closed) using controller **138**. Alternatively, pressure control device **136** and control valve **134** may suitably be independently controlled. However, controlling both devices with a common controller may be advantageous to better control the pressure at remote plasma unit **110**.

Optional integrated inlet manifold block **140** is designed to receive and distribute one or more gasses to reaction chamber **104**. An exemplary integrated inlet manifold block **140** is disclosed in U.S. Pat. No. 7,918,938 to Provencher et al., issued Apr. 5, 2011, entitled "High Temperature ALD Inlet Manifold," the contents of which are hereby incorporated herein by reference, to the extent the contents do not conflict with the present disclosure.

Catalyst **144** may be used to facilitate formation of one or more desired intermediate reactive species. For example, in the case when ammonia is used to make hydrazine, the catalyst may include iron, manganese oxide (MgO), or titanium oxide (TiO_2). Other suitable catalytic materials include noble metals, such as platinum, palladium, and rhodium.

To facilitate maintaining a steady-state plasma in remote plasma unit **110**, system **100** may include a conductance match region **146**, which may include an increased volume in a line between remote plasma unit **110** and pressure control device **136** to help match the fluid conductance in a line between remote plasma unit **110** and reactor **104** to a line between remote plasma unit **110** and vacuum source **112**.

FIG. **2** illustrates a method **200** for providing intermediate reactive species to a reaction chamber of a reactor. Method **200** includes the steps of: providing a first gas to the remote plasma unit (step **202**), controlling a pressure of the remote plasma unit (step **204**), forming a plasma in the remote plasma unit (step **206**), and forming intermediate reactive species from the first gas using the remote plasma unit, while maintaining steady-state conditions for the remote plasma unit (step **208**). As illustrated, method **200** may also include optional steps of purging the reaction chamber (step **210**), providing a second reactant to the remote plasma unit to form a second excited species (step **212**), and providing the second intermediate reactive species to the reaction chamber (step **214**). Method **200** may be used to deposit material onto a substrate, etch material from a surface of a substrate or reaction chamber, clean a substrate or portions of a reactor, and/or treat a surface of a substrate or a surface within a reactor. For example, method **200** may be used for PECVD and/or PEALD deposition processes and/or for etch or clean processes to etch material from a substrate or clean a portion of a reactor—e.g., a reactor fore line or other area that requires etching, cleaning, or treatment. Although illustrated with forming two intermediate reactive species, methods may include forming any desired number of intermediate reactive species.

During step **202**, one or more gasses are provided to a remote plasma unit (e.g., remote plasma unit **110**). The gas(ses) provided during step **202** may include one or more reactant gasses and/or one or more inert gasses. For example, ammonia or water, which are relatively safe precursors, may be provided to a remote plasma unit during step **202**.

During step **204**, an operating pressure of a remote plasma unit is controlled using an upstream pressure controller, such as pressure control device **136**, described above. The pressure may desirably be controlled by a closed-loop pressure controller. Controlling the upstream pressure of the remote plasma unit allows for formation or meta-stable intermediate reactive species. Furthermore, controlling the upstream pressure of the remote plasma allows for a more consistent distribution of species formed using the remote plasma unit, which allows for better process control of deposition, etch, and/or treatment processes.

Step **206** includes forming a plasma in a remote plasma unit, such as remote plasma unit **110**. A plasma may be formed by flowing one or more gasses (e.g., from one or more of sources **114-116**), providing a suitable pressure in remote plasma unit **110** (e.g., using vacuum source **112** and pressure control device **136**), and providing a sufficient electrical field across the one or more gasses within remote plasma unit **110**. A plasma may initially be formed using an inert gas (e.g., from source **118**) or may be formed with a reactant gas **114** and/or **116**.

During step **208**, intermediate reactive species from a remote plasma source (e.g., remote plasma unit **110**) are provided (e.g., pulsed) to a reaction chamber—e.g., using control valve **134**. As noted above, valve **134** and pressure control device may be simultaneously controlled using one or more controllers, such that as valve **134** allows increased or decreased flow to a reaction chamber, pressure control device **136** maintains a pressure at the remote plasma unit.

During step **210**, a reaction chamber of a system is purged—e.g., using gas from purge gas source **122**.

During optional steps **212** and **214** a second gas—e.g., a first or second reactant gas—is supplied to the remote plasma unit and a second intermediate reactive species is provided (e.g., pulsed) to the reaction chamber.

Although exemplary embodiments of the present disclosure are set forth herein, it should be appreciated that the disclosure is not so limited. For example, although the system and method are described in connection with various specific chemistries, the disclosure is not necessarily limited to these examples. Various modifications, variations, and enhancements of the system and method set forth herein may be made without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A remote plasma system comprising:

a reactor comprising a reaction chamber;

a remote plasma unit fluidly coupled to the reaction chamber and to a vacuum source;

a first gas source fluidly coupled to the remote plasma unit, wherein the first gas source comprises a precursor for intermediate reactive species;

a pressure control device in fluid communication with and interposed between the remote plasma unit and the vacuum source, wherein the pressure control device controls a pressure upstream of the pressure control device and wherein the pressure control device is a closed-loop pressure control device;

a control valve, between the remote plasma unit and the reaction chamber, to pulse the intermediate reactive species from the remote plasma unit to the reaction chamber and to maintain steady-state operation of remote plasma unit; and

a controller coupled to the pressure control device and to the control valve and configured to control the pressure control device and the control valve to maintain steady-state operation of the remote plasma unit when the intermediate reactive species are pulsed to the reaction chamber using the control valve to switch a flow of the intermediate reactive species between the reaction chamber and the vacuum source.

2. The remote plasma system of claim **1**, further comprising a flow control unit coupled to the first gas source.

3. The remote plasma system of claim **1**, wherein the reactor is selected from the group consisting of a plasma-enhance chemical vapor deposition reactor, a plasma-enhanced atomic layer deposition reactor, a plasma-enhanced etch reactor, a plasma-enhanced clean reactor, and a plasma-enhanced treatment reactor.

4. The remote plasma system of claim **1**, wherein the control valve is a fast-response pneumatic valve.

5. The remote plasma system of claim **1**, further comprising an integrated inlet manifold block.

6. The remote plasma system of claim **1**, further comprising a catalyst between the remote plasma unit and the reaction chamber.

7. The remote plasma system of claim **6**, wherein the catalyst is between the remote plasma unit and the control valve.

8. The remote plasma system of claim **6**, wherein the catalyst comprises a material selected from the group consisting of, iron, magnesium oxide (MgO), titanium oxide (TiO2), platinum, palladium, and rhodium.

9. The remote plasma system of claim **1**, further comprising a conductance match region between the remote plasma unit and the pressure control device.

10. The remote plasma system of claim **1**, wherein the remote plasma unit is an inductively coupled plasma unit.

11. The remote plasma system of claim **1**, wherein the remote plasma unit is a microwave plasma unit.

12. The remote plasma system of claim **1**, wherein the first gas source comprises one or more of ammonia (NH3), water vapor (H2O), hydrogen peroxide (H202), MMH (mono methyl hydrazine), UDMH (unsymmetrically dimethyl hydrazine), 02/H2, N2/H2, and H2S.

13. A plasma-enhanced chemical vapor deposition system comprising:

a deposition reactor comprising a reaction chamber;

a remote plasma unit fluidly coupled to the reaction chamber and to a vacuum source;

a first reactant source coupled to the remote plasma unit, wherein the first reactant source is a precursor for intermediate reactive species;

a pressure control device in fluid communication with and interposed between the remote plasma unit and the vacuum source, wherein the pressure control device controls a pressure upstream of the pressure control device, and wherein the pressure control device is a closed-loop pressure control device;

a control valve, between the remote plasma unit and the reaction chamber, to pulse the intermediate reactive species from the remote plasma unit to the reaction chamber and to maintain steady-state operation of remote plasma unit; and

a controller coupled to the pressure control device and to the control valve to control the pressure control device and the control valve, the controller configured to maintain steady-state operation of the remote plasma unit when intermediate reactive species are pulsed to the reaction chamber using the control valve to switch a flow of the intermediate reactive species between the reaction chamber and the vacuum source.

14. The plasma-enhanced chemical vapor deposition system of claim **13**, further comprising a catalyst between the remote plasma unit and the control valve.

15. The plasma-enhanced chemical vapor deposition system of claim **14**, wherein the catalyst comprises a material selected from the group consisting of, iron, magnesium oxide (MgO), titanium oxide (TiO2), platinum, palladium, and rhodium.

16. The plasma-enhanced chemical vapor deposition system of claim **13**, further comprising a conductance match region between the remote plasma unit and the vacuum source.

17. The plasma-enhanced chemical vapor deposition system of claim **16**, wherein the conductance match region is between the remote plasma unit and the pressure control device.

18. The plasma-enhanced chemical vapor deposition system of claim **13**, wherein the first reactant source comprises one or more of ammonia (NH3), water vapor (H2O), hydrogen peroxide (H202), MMH (mono methyl hydrazine), UDMH (unsymmetrically dimethyl hydrazine), 02/H2, N2/H2, and H2S.

19. A remote plasma system comprising:

a reactor comprising a reaction chamber;

a remote plasma unit fluidly coupled to the reaction chamber and to a vacuum source;

a first gas source fluidly coupled to the remote plasma unit, wherein the first gas source comprises a precursor for intermediate reactive species;

a pressure control device in fluid communication with and interposed between the remote plasma unit and the vacuum source, wherein the pressure control device controls a pressure upstream of the pressure control device and wherein the pressure control device is a closed-loop pressure control device;

a control valve, between the remote plasma unit and the reaction chamber, to pulse the intermediate reactive species from the remote plasma unit to the reaction chamber and to maintain steady-state operation of remote plasma unit;

a controller coupled to the pressure control device and to the control valve and configured to control the pressure control device and the control valve to maintain steady-state operation of the remote plasma unit when the intermediate reactive species are pulsed to the reaction chamber using the control valve to switch a flow of the intermediate reactive species between the reaction chamber and the vacuum source; and

a catalyst between the remote plasma unit and the control valve, the catalyst comprising a material selected from the group consisting of, iron, magnesium oxide (MgO), titanium oxide (TiO2), platinum, palladium, and rhodium.

20. The remote plasma system of claim **19**, further comprising a conductance match region between the remote plasma unit and the vacuum source.

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